AIR FORCE OFFICE of SCIENTIFIC RESEARCH [AFOSR]
Manager of the Basic Research Investment for the Air Force

Research HIGHLIGHTS

SEP OCT 01

A New Approach to an Old (Radar) Signal

Developments in research funded by the Mathematics and Space Sciences Directorate of the Air Force Office of Scientific Research (AFOSR/NM) have provided a mathematical theory for a new radar wave.

This revolutionary radar wave holds great promise in aiding with rapid and accurate target identification through foliage and beneath soil, better than any radar currently in use.

Tree canopies, soil, and many other media, such as water, human tissue and radar-absorbing material disperse electromagnetic energy — in this case radar waves. Like a prism, this affects the transmission of some electromagnetic waves.

A monofrequency wave is minimally affected by dispersion, because dispersion is a frequency dependent event. More accurately, each frequency is affected differently. For example, propagation velocity within a dispersive media depends on frequency, and also applies to the strength of attenuation. But, if there is only the one frequency (mono), then the difference is of minor importance. When the impinging signal is spectrally rich (multi-frequency), then interesting things can happen. In this case, the square-wave modulated sine forms a “precursor.”

When the square-wave sine encounters the media, it disperses and loses energy and it gets rearranged by the media and continues traveling through it. Additionally, the square-wave sine does not resemble its original signal. The new signal, called a precursor, continues on passing through the medium, hits the target and returns a signal without any further changes. The surprise is that the dispersive media concocts the signal, if you aim the square-wave at it. It stresses the dispersive media in a way that causes it to respond in this manner. Current radar pulses do not stress the media.

The precursor contains both high and low frequency components and may be the key to allowing scientists to receive a detailed signal on targets.

Once formed, the precursor continues to travel with virtually no change in form, but does experience a gradual decrease or loss in amplitude. While a monofrequency wave would see its amplitude diminish exponentially with depth as it penetrates the dispersive media, the precursor’s amplitude diminishes algebraically. This results in more energy being delivered deeper and available for reflection from an object, like a tank parked beneath a forest canopy or a bunker hidden under the soil.

Moreover, the short wavelength content of the precursor delivers back to the receiver a greater spatial resolution or target detail. This contrasts with the current practice of illuminating forest canopies with gently modulated radar waves.

Monofrequencies, greater than those currently used, lose their signal strength so severely, they don’t make it through the forest canopy. While these shorter wavelengths do

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Functionally-Graded, Thin Film Shape Mem

An Air Force Office of Scientific Research-sponsored research program at the Active Materials Lab (AML), University of California, Los Angeles has reported a significant breakthrough in the manufacture of functionally graded, thin film shape memory alloy (SMA) micro-actuators.

Shape memory behavior represents a material's ability to recover from large deformations (of approximately 10%) with a thermally-induced phase transformation. The shape memory material is deformed at room temperature, causing a permanent deformation similar to the deformation of copper when wound around your finger. Unlike copper, however, when heated above a critical temperature (typically around 100°C), shape memory materials immediately spring back to their original, "memorized" shape. One of the most widely used shape memory materials is the binary alloy of nickel (Ni) and titanium (Ti).

FIGURE 1

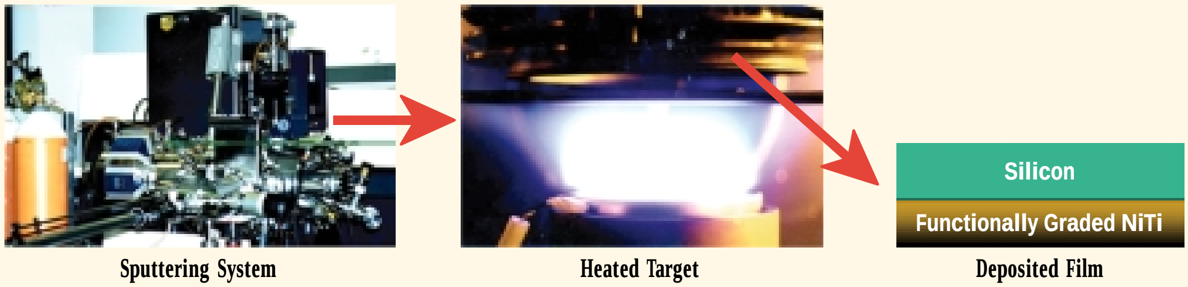


Figure 1/Above: Photograph of sputtering system, heated target, and illustration of functionally graded shape memory materials

Significantly, the large deformations generated during the original memory "spring back" of NiTi produce the largest energy density of any smart material available—an order of magnitude larger than piezoelectric materials. However, slow cycling speeds (one hertz) and one-way actuation limits the usefulness of shape memory alloys in many engineering applications. To overcome this problem, AML researchers developed micron-sized (one millionth of an inch), thin film actuators, thus increasing the possible cycling speed from one hertz to one hundred hertz. However, producing the thin films necessary for such a large improvement was found to be problematic due to the loss of Ti during the sputtering deposition process whereby the particles are transferred to a substrate. To address this issue, AML researchers pioneered a novel approach that limits the Ti loss during sputter deposition by using a heated target (see Figure 1). They found that target temperature influences the Ti dispersion during sputtering, and, as such, could be used to control the composition of the film during deposition. This advancement subsequently led to the development of functionally-graded, thin film material.

FIGURE 2

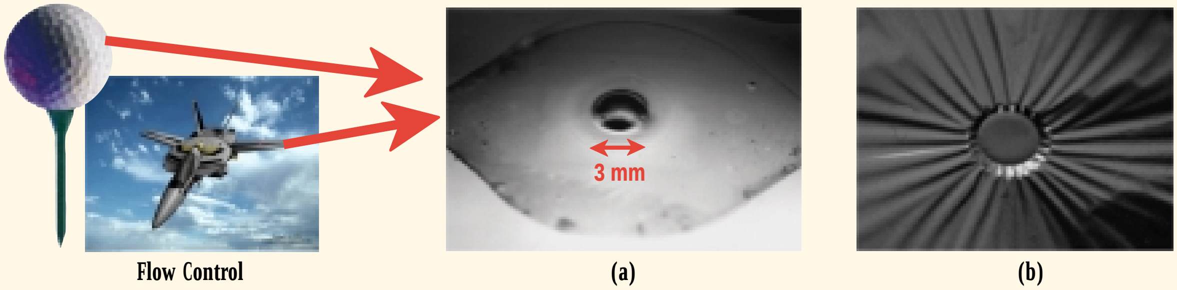


Figure 2/Above: Flow control applications using the (a) bubble activator concept and (b) a more complex geometry

By varying the target temperature during sputtering, AML researchers produced thin film with a gradation in Ti content through the thickness, therefore resulting in what we term functionally-graded thin film. As the Ti content increases in the micron-thick film, the material properties change from pseudo-elastic

ory Alloy Micro-Actuators

(similar to rubber) to shape memory. The seamless integration of pseudo-elastic with shape memory characteristics produces a two-way actuator—one of the first materials to exhibit this behavior. When the actuator is heated with a small electrical current, the actuator deforms into a “memorized” shape. Upon cooling, the material returns to its original shape. Due to its small dimensions, the cyclic response of the device can approach 100 Hz, over an order of magnitude improvement when compared to commercially-available shape memory material. Given that power output is the product of energy times frequency, the power output of these small-scale actuators is considerable.

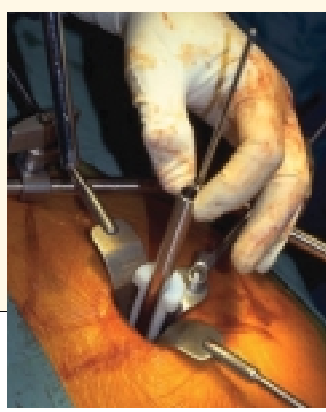
Using micro-electro-mechanical systems (MEMS) manufacturing techniques, AML researchers began manufacturing micro-actuators. One of the first actuators developed was a bubble actuator for flow control on aircraft systems (See Figure 2). The bubble actuator’s size is comparable to the geometry of an inverted golf ball dimple. However, unlike a golf ball dimple, the bubble actuator is active. When a small current passes through the bubble, it dimples outward into the flow (Figure 2a). When the current is off, the film quickly cools and the dimple returns to the original shape. Correct placement on a missile or an aircraft may decrease drag and provide improved aerodynamic maneuverability for the structure. Further experimentation by AML researchers investigated the use of more sophisticated actuation geometries (Figure 2b) to generate more complex flow patterns for enhanced control.

In addition to flow control actuators, AML researchers fabricated a micro-wrapper using the functionally-graded thin film shape memory material. The overall dimension of the micro-wrapper arms is one hundred microns, approximately the diameter of a human hair. This micro-wrapper may be used to manipulate micro-organisms or possibly used in minimally invasive surgery to remove anomalies such as tumors (see Figure 3). In Figure 3c, the micro-wrapper has a small current passing through it to maintain the flat shape. Upon removal of the current, the small arms close (Figure 3d) to form a cage approximately 50 microns in diameter. Current biomedical applications for NiTi shape memory alloys include vena cava filters and surgical stents. With the advent of thin film MEMS shape memory devices supported by AFOSR, a much larger array of biomedical devices is possible.

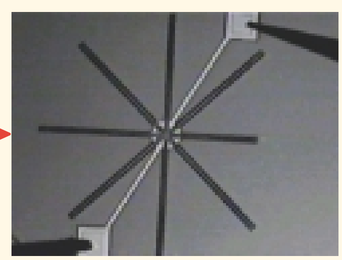
Recent DARPA-supported work at the AML facility includes the introduction of the thin film shape memory actuator into a micro-pump actuator. The actuator is designed to articulate the nosecone of a Compact Kinetic Energy Missile (CKEM) being designed by Raytheon for a future combat vehicle system.

Dr. Daniel Segalman, AFOSR/NA

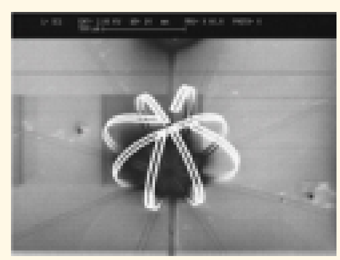
FIGURE 3



(LEFT): Minimal invasive surgery



(c)



(d)

Figure 3/Above: Medical device applications using the micro-wrapper (c) open due to applied current and (d) closed around a 50 micron particle.

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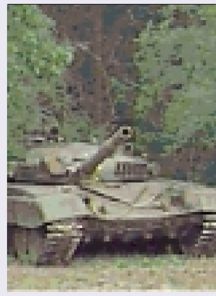

reflect from objects beneath the canopy, the detail returned cannot distinguish between a tank and a metal barrel.

The theory, as described above, was predicted under an AFOSR university grant and experimentally verified in water by scientists from the Air Force Research Laboratory Human Effectiveness Directorate at Brooks AFB, Texas. The original research revolved around the concern for Air Force personnel, such as radar technicians, being exposed to various electromagnetic energies.

The greatest challenge facing scientists in exploiting this phenomenon of faster and more accurate target acquisition and recognition is that a great deal more research is required to fabricate the necessary hardware. We currently cannot produce a square-wave modulation without first pursuing research on very fast switches—about 1Volt/meter/nanosecond—with the ability to handle the currents within radars. It’s also possible that refined signal processing, beyond the standard matched filter, should accompany these novel radars.

Experiments are currently being conducted at different locations on various aspects of this new signal breakthrough. Although we may be many years away from a practical demonstration, a new approach to radar is now on the horizon.

Dr. Arje Nachman, AFOSR/NM

AFOSR Program Manager Receives AFRL Fellows Award

The Air Force Research Laboratory (AFRL) recently selected Dr. Harold Weinstock as one of four outstanding scientists and engineers for the AFRL fellows award. The award recognizes a person's career contributions in research and development and technical program management.

Dr. Harold Weinstock

"AFRL fellows are our top researchers and exemplify the tremendous human capital we have throughout the lab," said Maj. Gen. Paul Nielson, AFRL commander. "The laboratory relies on our fellows for advice on substantial issues and to represent the laboratory's endeavors and interest in the national and international scientific and engineering communities."

The selection committee considers both military and civilian scientists and engineers, who have at least seven years of active federal service and three consecutive years with AFRL preceding the nomination.

Weinstock first worked as a professor for 21 years at the Illinois Institute of Technology (IIT). While on sabbatical from IIT, he worked for the Office of Naval Research in their Chicago office, visiting his Washington D.C. counterparts occasionally. When he learned of an opening within AFOSR as a program manager in the area of superconductivity, Weinstock joined the AFOSR family as an IPA and then a full-time government employee in 1986. He said the opportunity to continue his superconductivity research contributed to his decision.

At the University of Maryland, he participates in studying Non-Destructive Inspection methods using a Superconducting Magnitometer, or a Superconducting Quantum Interference Device (SQUID). Weinstock has worked this field for nearly 19 years and was the first person to use the SQUID to look for defects, holes and cracks in pipes and other metals.

As a program manager for AFOSR's Physics and Electronics Directorate, Weinstock oversees work involving superconductivity in magnetic materials and nanoelectronics. He's most proud of convincing others in his field to use the SQUID to detect defects below the surface of aircraft structures. It also is the only equipment sensitive enough to measure corrosion currents as it occurs. As a result of Weinstock's work, the Air Force is able to make models of corrosion to evaluate an aircraft's longevity and to predict possible repair schedules, before it's too late.

Besides assessing future corrosion growth rates, the SQUID also has influenced the medical and geophysical fields. In medicine, the SQUID is a promising application to help doctors survey magnetic field patterns associated with heart arrythmias. It may have the ability to replace current techniques that put patients at risk.

In the area of geophysics, the SQUID has the potential to replace expensive techniques used in prospecting for oil and minerals. A pioneer in this field, Weinstock has directly influenced the current developments of the SQUID.

Weinstock's affiliation with AFRL has contributed to the lab's reputation as a world leader in research and development.

Research Highlights

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Research Highlights is published every two months by the Air Force Office of Scientific Research. This newsletter provides brief descriptions of AFOSR basic research activities including topics such as research accomplishments, examples of technology transitions and technology transfer, notable peer recognition awards and honors, and other research program achievements. The purpose is to provide Air Force, DoD, government, industry and university communities with brief accounts to illustrate AFOSR support of the Air Force mission. *Research Highlights* is available on-line at:

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